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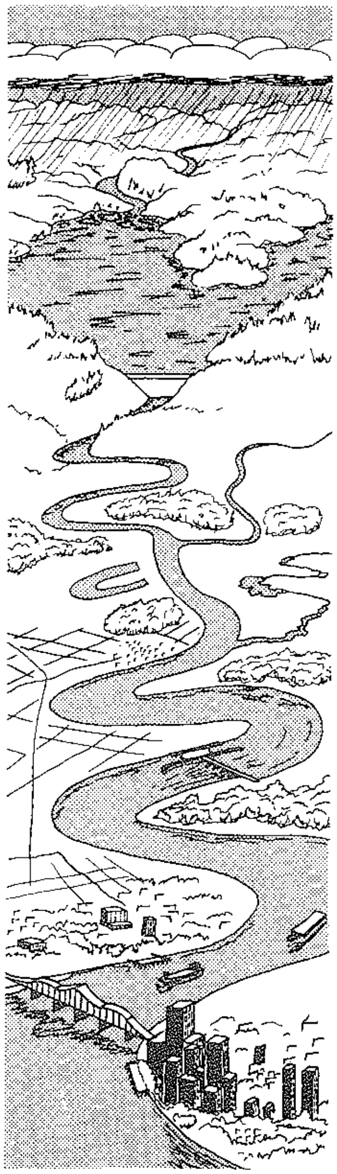

WATER OPERATIONS TECHNICAL SUPPORT PROGRAM

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WATER QUALITY ENHANCEMENT TECHNIQUES USED WITHIN THE CORPS OF ENGINEERS

by

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This report examines the findings of a US Army Corps of Engineers (CE) questionnaire sent to each CE District in 1988. This questionnaire requested information regarding project authorization, design, water quality attributes, and water quality enhancement techniques. The degree of success, approximate cost, and any associated disadvantages of the particular techniques were also requested.

Responses were received from 17 Districts representing 9 Divisions. Enhancement techniques for 96 projects were reported. The water quality concerns were categorized according to location (tailwater, pool, or lock and dam) and are discussed in respective order by frequency of occurrence from questionnaire responses. Twenty-eight different enhancement techniques were identified with some projects listed as still under investigation. Of the categories of techniques, operational methods were reported to be the most successful.

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PREFACE

This report was prepared by the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES), as part of the Water Quality Management for Reservoirs and Tailwaters Demonstration of the Water Operations Technical Support (WOTS) Program, sponsored by Headquarters, US Army Corps of Engineers (HQUSACE). Mr. David P. Buelow, HQUSACE, is Technical Monitor. Mr. J. Lewis Decell is Program Manager of WOTS at WES.

This report was prepared by Dr. Richard E. Price of the Reservoir Water Quality Branch (RWQB), Hydraulic Structures Division (HSD), HL, under the direct supervision of Dr. Jeffery P. Holland, Chief, RWQB, HL, and Dr. Robert H. Kennedy, Aquatic Processes and Effects Group, Ecosystem Research and Simulation Division, Environmental Laboratory, (EL), WES, and under the general supervision of Mr. Glenn A. Pickering, Chief, HSD, and Mr. Frank A. Herrmann, Jr., Chief, HL. Dr. John Harrison was Chief, EL. This report was edited by Ms. Lee T. Byrne, Information Technology Laboratory.

Commander and Director of WES during publication of this report was COL Larry B. Fulton, EN. Dr. Robert W. Whalin was the Technical Director.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
miles (US statute)	1.609347	kilometres

WATER QUALITY ENHANCEMENT TECHNIQUES USED WITHIN THE CORPS OF ENGINEERS

PART I: INTRODUCTION

1. The US Army Corps of Engineers (CE) operates approximately 780 water resources projects across the continental United States, authorized for purposes such as flood control, navigation, hydropower generation, irrigation, water supply, fish and wildlife habitat, and recreation. The CE Districts and operating Divisions, which are the major functional entities of the CE, are responsible for operation and maintenance of these projects. In addition, public laws, executive orders, and other regulations give these field offices responsibility for water quality management at CE projects.

2. Through implementation of water quality management programs at the Districts, a number of water quality concerns have been identified at reservoir projects. These concerns range from deviations from State and Federal water quality standards at project tailwaters to enhancement needs to improve in-lake biological productivity at the projects. Typical tailwater concerns involve rapid change in release temperature due to hydropower generation, low dissolved oxygen (DO) in the project tailwaters, and trace elements in the release. In-lake concerns are usually associated with the effects of eutrophication such as hypolimnetic anoxia, but also include concerns with aquatic vegetation. Other concerns include nonpoint source pollutants such as acid mine drainage and turbidity, as well as point source pollutants.

3. To identify techniques that the CE Districts use in their respective water quality management programs, a comprehensive questionnaire (Appendix A) was prepared and sent to each District in 1988. This questionnaire requested information regarding project authorization, design, and water quality attributes. In addition, a section requesting specific information regarding water quality enhancement techniques was included. This section (Section C) was designed to identify the types of water quality concerns the Districts routinely encounter and control through enhancement techniques. The degree of success, approximate cost, and any associated disadvantages of the particular technique were also requested. This information was to be based on the District's evaluation and perspective rather than on rigorous scientific proof of the technique's effectiveness.

4. Responses were received from 17 Districts representing 9 Divisions. Enhancement techniques for 97 projects were reported (Table 1). Although a

project may have had several concerns, only those for which an enhancement technique was currently being investigated or applied were reported. Enhancement techniques that were tested or applied prior to the current technique were usually not reported. Therefore, the techniques reported here should not be construed as an exhaustive listing of water quality enhancement techniques, but rather as an indication of current water quality activities at CE projects.

5. The reported water quality concerns were categorized according to location (tailwater or pool, or lock and dam) and are discussed in respective order by frequency of occurrence from questionnaire responses. For example, under tailwater concerns, release temperature fluctuation was the most

Table 1

Number of Projects Where Enhancement Techniques Were Reported

US Army Engineer District/Division	Number of Projects
Vicksburg	3
St. Louis	5
Kansas City	6
Omaha	17
Baltimore	11
Norfolk	1
Rock Island	1
New England	3
Portland	17
Walla Walla	2
Huntington	1
Nashville	4
Pittsburgh	13
Los Angeles	1
Fort Worth	1
Little Rock	3
Tulsa	8
Total	97

commonly reported concern, followed by low DO. Enhancement techniques used for each concern are reported including a relative assessment of degree of success and, when available, relative costs. References that appear with some techniques are given to provide more detailed information about the particular technique under discussion and did not necessarily come from the questionnaire responses.

PART II: TAILWATER ENHANCEMENT NEEDS AND TECHNIQUES

6. The water quality concerns reported from most project tailwaters were the result of the occurrence of hypolimnetic anoxia and/or density stratification in the reservoir on a seasonal basis (Kennedy, Gunkel, and Gaugush 1988). These tailwater concerns fit into six major categories (Table 2). Release temperature (too warm, too cool, or too much fluctuation of the temperature) was the most commonly mentioned concern (21 projects). Low DO was listed as a major concern at eight projects. This was sometimes manifested as a fish kill downstream during the summer and fall stratification periods. Concerns with trace metals and compounds (iron (Fe), manganese (Mn), and hydrogen sulfide (H_2S)) were reported from four projects. Nitrogen supersaturation in the tailwaters of three projects was discussed as a concern, but only in the Columbia River system in the Pacific Northwest. Miscellaneous concerns involved organic sediment accumulation downstream of one project and ice formation downstream of one project that created difficulty with flood-control operations.

Release Temperature

7. Concerns with release temperatures were most often described as the release of cold hypolimnetic water during the stratified period, usually from a peaking hydropower project. Some projects, however, were reported to suffer from cold releases during low-flow or nongeneration periods. The methods used to release warmer water centered on selective withdrawal techniques. This technique involves prediction of the flow distribution resulting from water being released from a stratified impoundment and selectively applying that capability to withdraw water of a desired quality (Wilhelms 1986). At Cowanesque Lake in Baltimore District (NAB), concern with release temperature was eliminated using selective withdrawal. Water quality control objectives were analyzed and prioritized to control the release temperature for fisheries downstream. Using numerical models and a technique developed by NAB (Lee 1986), the system capacity and design were developed to meet the project requirements. Raystown Lake, also in NAB, released water that was too cool for aquatic species downstream. This was controlled by use of a selective withdrawal system. Selective withdrawal was also used to enhance the cold water fishery downstream of Kettle Creek Lake, also in NAB. In Kansas City

Table 2

Summary of Water Quality Enhancement Technique Applications at CE Projects

Water Quality Concern	Technique Applied	Total Number of Projects	Degree of Success		
			Successful	Marginal	Unknown
	Tailwater Technique Applications				
Temperature	Selective withdrawal	9	2	3	4
	Weir	3	3	--	--
	Operational modification	2	1	1	--
	Under study	7	--	--	7
Low DO	Operational modification	6	6	--	--
	Under study	2	--	--	2
Trace metals	Operational modification	3	3	--	--
	Localized mixing	1	1	--	--
Acid mine drainage	Operational modification	2	2	--	--
N supersaturation	Structural modification	3	--	3	--
Miscellaneous	Operational modification	2	1	--	1
	In-Lake Enhancement Technique Applications				
Turbidity	Drawdown and planting	12	1	--	11
	Dredging	1	--	1	--
	Operational modification	2	2	--	--
	Inflow diversion	1	1	--	--
	Under study	4	--	--	4
Eutrophication	Olszenski tube	1	--	--	1
	Destratification	2	1	1	--
	Hypolimnetic aeration	1	--	--	1
	Copper sulfate	1	--	1	--
	Pool fluctuation	1	--	1	--
	Structural modification	1	--	--	1
	Wetland creation	1	--	--	1

(Continued)

Table 2 (Concluded)

Water Quality Concern	Technique Applied	Total Number of Projects	Degree of Success		
			Successful	Marginal	Unknown
	In-Lake Enhancement Technique Applications (Continued)				
	Best management practice	1	--	--	1
	Under study	2	--	--	2
Macrophytes	Herbicides	6	--	4	2
	Grass carp	1	--	--	1
Acid mine drainage	Operational modification	4	3	--	1
	Selective withdrawal	1	1	--	--
	Liming	2	2	--	--
Total dissolved solids (TDS)	Operational modification	1	1	--	--
Point source (oil wells)	Plug wells	1	1	--	--
Mercury (Hg)	Under study	1	--	--	1
	Lock and Dam Enhancement Technique Applications				
Low DO	Operational modification	7	7	--	--

District (MRK), the stop-log gaps in the release structures at Smithville, Hillsdale, and Clinton projects (which were not designed with selective withdrawal ports) were modified with apertures to allow selective withdrawal of warmer water during low-flow conditions. These apertures were constructed using a stop-log frame without a skin (Figure 1). To provide the selective withdrawal capacity, the stop logs were installed with three apertures at the desired elevation. Pomme de Terre project, also in MRK, was modified by addition of sheet metal plates to the trash racks of the low-flow bypass to raise the level of withdrawal and increase the temperature of releases; but, this application has been evaluated as marginally successful. During the stratified periods, low-flow releases are made within normal release temperature requirements; however, when releases exceeded 50 to 100 cfs,* operation of the sluice gates was required, resulting in the release of cold, low-DO hypolimnetic water.

8. A similar technique has been proposed for intakes at Lake Greeson in Vicksburg District (LMK) to control the temperature of hydropower releases (Price and Johnson 1986, Johnson 1987). The proposed modification, which was simulated in a numerical model, would increase both the release DO and temperature during the late summer and fall (Figure 2).

9. Martin's Fork Lake in Nashville District (ORN) was designed with three selective withdrawal intakes to provide release temperatures similar to preproject conditions. This technique was successful and also improved the release DO.

10. Submerged weirs have been used as an effective selective withdrawal alternative in hydropower projects to minimize the withdrawal of poorer quality hypolimnetic water during hydropower releases (Furdek 1986, Linder 1986). The technique involves construction of an impermeable submerged weir upstream of the intake structure. The crest of the weir is located to constrict the lower withdrawal limit and thereby release the desired quality from the epilimnion (Figure 3). Rock weirs were constructed at Stockton and Harry S. Truman projects in MRK and at Clarence Cannon Dam (Mark Twain Lake) in St. Louis District (LMS). These have been successful, although all three projects have reported low temperature and DO of releases when the thermocline formed at an elevation above the weir crest. For example, continuous

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

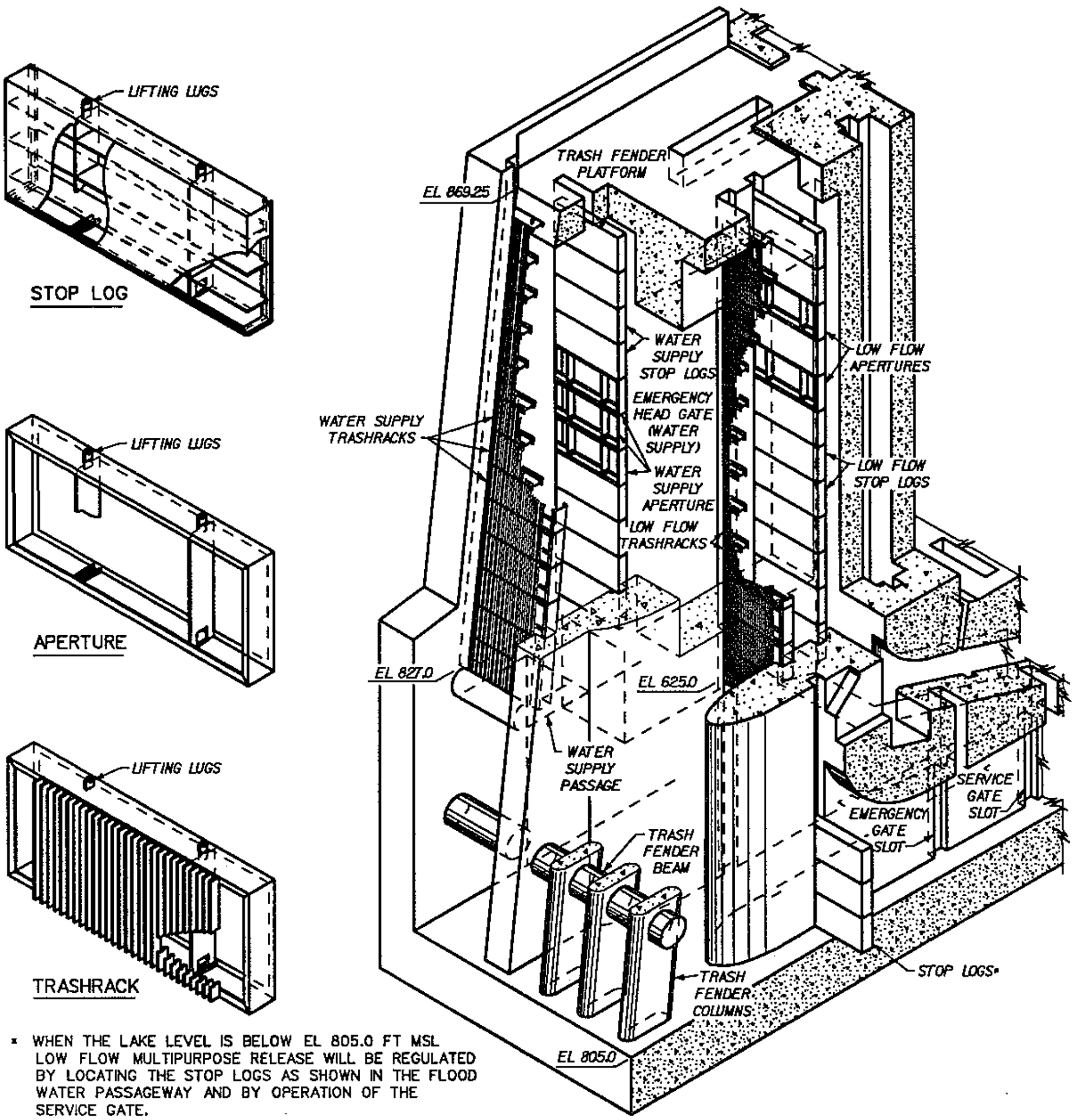

Figure 11. Smithville Reservoir intake structure with appurtenances (furnished by MRK)

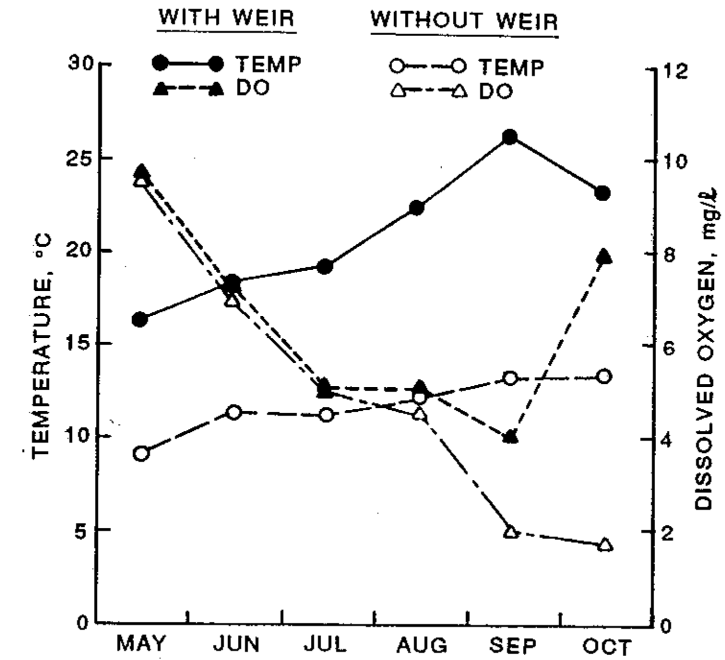

Figure 2. Lake Greeson predicted release temperature and DO with and without plated trashracks (from Price and Johnson (1986))

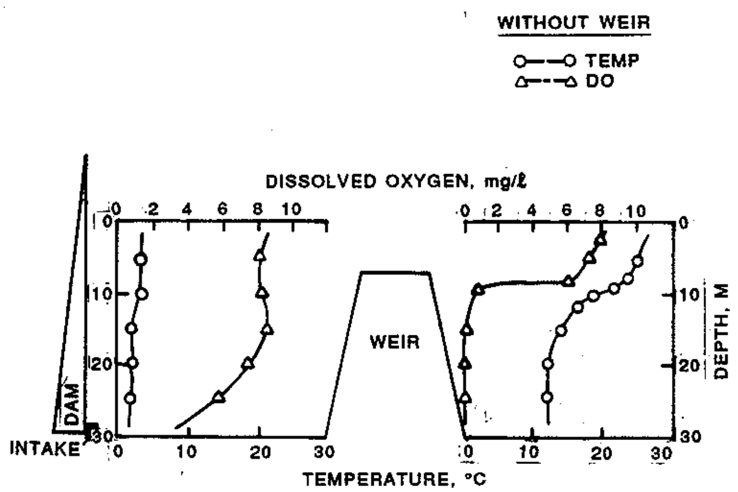

Figure 3. Temperature and DO profiles during hydropower generation at Stockton Dam (from Linder (1986))

monitoring of water quality in the Clarence Cannon Dam tailby has indicated that following cessation of hydropower generation, the temperature and DO began to decline. This was noted when the thermocline in the lake formed at an elevation higher than the crest of the submerged weir. When generation ceased, the area between the weir and the dam stratified. With the turbine intakes located near the bottom, hypolimnetic water, which is cool and low in DO, began to leak through the wicket gates and migrate downstream. Upon the initiation of hydropower generation, the weir functioned as designed and allowed the hydropower project to release epilimnetic quality water (Figure 4).

11. Lake Wallula in Walla Walla District was reported to have difficulty with thermal shock on smolt migration through the dam. During downstream migration, smolt were stressed in the fish transportation system because of warm surface water being drawn into the system along with cool hypolimnetic flow. Corrective techniques are centering on operational changes that modify the flow conditions; however, investigations are still underway.

12. At Lake Red Rock in Rock Island District, downstream fish kills observed with high discharge events that utilized the tainter gates were the

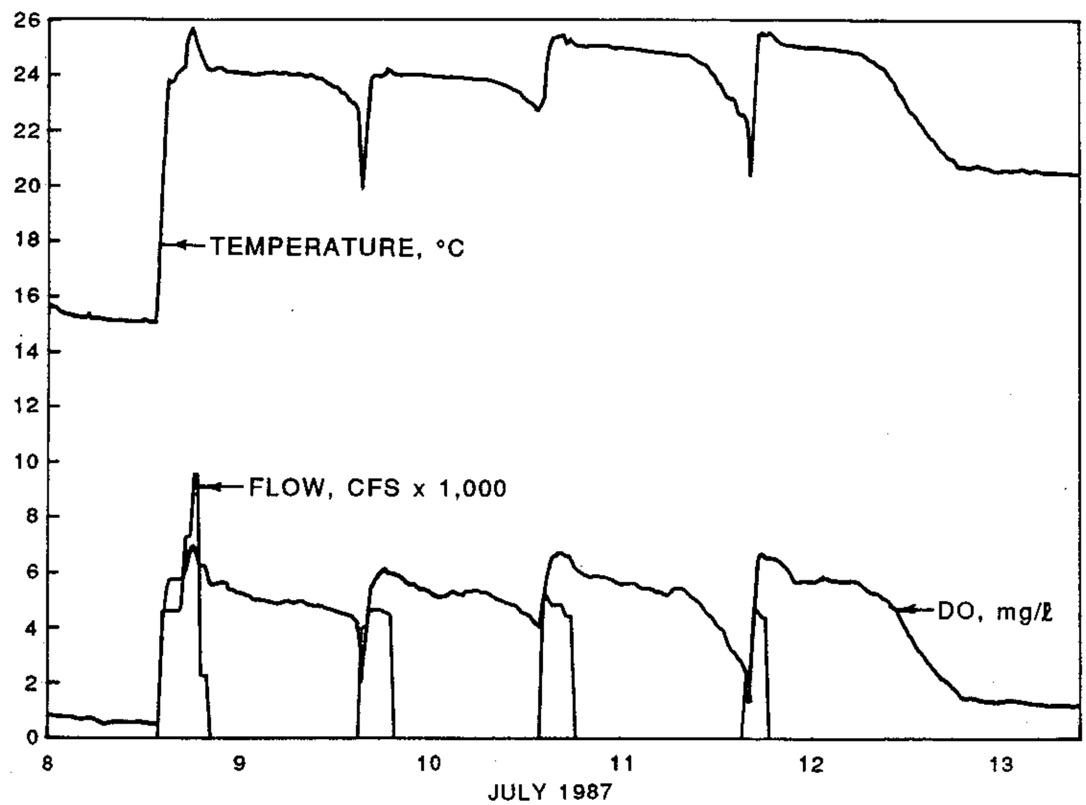

Figure 4. Mark Twain Lake release temperature, DO, and Volume from 8 to 13 July 1987 (data furnished by LMS)

result of either a rapid change in temperature downstream during the spring flows or gas supersaturation. This was partially corrected by discontinued use of the tainter gates except when called for by the water control plan. This technique has been only marginally successful, and investigations are continuing.

13. The river downstream of Savage River Dam in NAB experienced fluctuating temperature that reduced fish productivity. A technique that involved limiting uncontrolled spillway flow by evacuating stored hypolimnetic water during high-flow events increased the overall reservoir temperature. This in turn reduced the fluctuation of release temperature. The technique was evaluated as successful at no costs.

14. Control of water temperature for fish spawning downstream of Lost Creek project in Portland District (NPP) was reported as a concern, and investigations are underway to identify enhancement alternatives. Green Peter, Foster, Detroit, Cougar, Big Cliff, and Blue River Reservoirs, also in NPP, were reported to have unfavorable release temperatures for anadromous fish (too cold in the spring and summer and too warm in the fall). This concern was still under investigation at these projects.

Dissolved Oxygen

15. Low DO in releases has contributed to fish kills below a number of CE projects. These were reported as occurring during the summer stratified period when the hypolimnia became devoid of oxygen. The most commonly reported enhancement technique was a modification of the release operation. For example, Eufaula Reservoir and Lake Texoma in Tulsa District (SWT) and Carlyle Lake in LMS supplemented hydropower releases with spillway releases when the DO in the tailwaters began to drop. These spillway releases were subject to increased downstream energy dissipation and therefore greater reaeration potential than hydropower releases.

16. Mobile District has recognized a similar problem in the tailbay at Walter F. George Lock and Dam. During nongeneration periods, the DO in the tailbay begins to decline. As shown in Figure 5, releases from the spillway gates increase turbulence in the tailbay, thereby increasing in DO. This technique, which was also used at Lake Shelbyville in LMS to control H_2S in the tailwaters, was reported as successful; however, it does reduce the available head for hydropower generation.

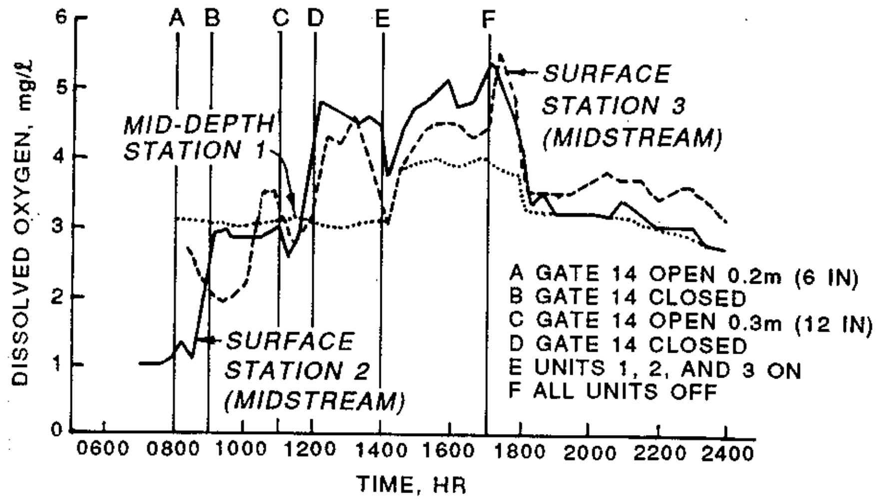

Figure 5. Concentrations of DO downstream of Walter F. George Lock and Dam during water quality tests in 1986 (from Findley and Day (1987))

17. A slightly different concern was identified at Waurika Lake and Lake Wister in SWT. These projects were suffering from fish kills in the stilling basin subsequent to shut down of spillway releases. The fish were being trapped in the stilling basin and, through normal respiration, were depleting the DO. This problem was solved by tapering the shut-down sequence to allow adequate time for the fish to escape downstream.

18. Table Rock Lake in Little Rock District (SWL) has experienced difficulties with low DO in the hydropower releases. Although several pilot tests have been conducted to improve the release DO (Morehead 1986), investigations are still underway. Lake Sakakawea in Omaha District (MRO) was reported to have similar concerns and was also in a similar status.

Trace Metals

19. Several projects were reported to have concerns with trace metals (Fe, Mn), odor (H_2S), and/or pH in the release. In most cases, these concerns were the direct result of the stratification cycle. Density stratification of reservoirs acts to inhibit reaeration of the hypolimnion. If the DO demand is great enough, anoxic conditions will occur in the hypolimnion resulting in release of Fe, Mn, and H_2S from sediments. If the release structure withdraws from the hypolimnion, these trace constituents will be released downstream.

20. The Portland District successfully controlled the release of H_2S from Fall Creek Reservoir by increasing the project discharge. During the first 2 years of project operation, lethal concentration (to salmonids) of H_2S formed in the hypolimnion. During the late summer when discharges were on the order of several hundred cubic feet per second, no impacts of the H_2S on downstream fish were observed. However, when the discharge was reduced to less than 100 cfs, fish were killed downstream of the project (Water Resources Research Institute 1969). Thus, the turbulence in the stilling basin associated with the higher flows provided greater reaeration potential in the tailwater, thereby dissipating the H_2S in the tailwaters.

21. Norfolk District successfully controlled a similar situation at Gathright Dam by releasing water from higher elevations in the pool, but this procedure also reduced the flexibility of operation of the water quality gates.

22. Releases from J. Percy Priest Reservoir in ORN were improved by use of localized mixing to control trace metals and H_2S in the releases and to attain DO objectives (Sneed 1988, Price and Holland 1988). This technique was designed to mix higher quality epilimnetic water with lower quality hypolimnetic water in front of the hydropower intakes, thereby improving release quality (Figure 6). This system was reported to be successful, but did not eliminate the H_2 odor in the release.

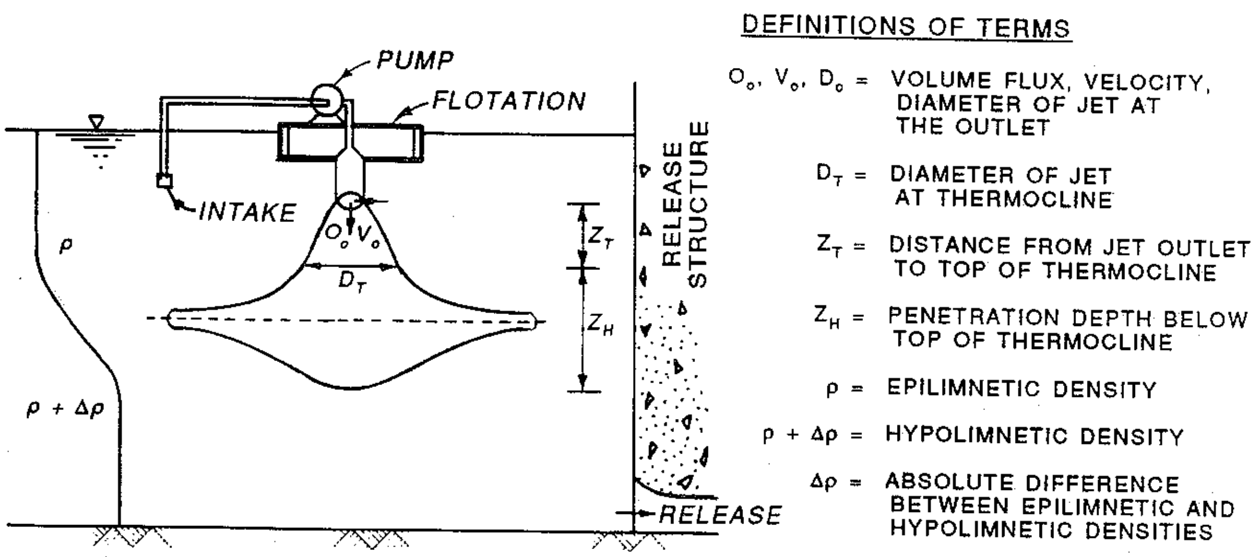

Figure 6. Schematic of localized mixing system for dilution of hydropower releases at J. Percy Priest Reservoir

23. Old Hickory Lake, also in ORN, was operated to reduce Mn concentrations downstream for a water supply intake. Releases from J. Percy Priest Reservoir containing high concentrations of Mn were diluted with releases from Old Hickory. This coordination of releases was successful; however, some flexibility in releases for hydropower from Old Hickory was lost.

24. Foster Joseph Sayers Dam in NAB was operated to control acid mine drainage in the West Branch Susquehanna River. By controlling alkaline releases from the reservoir, blending with lower pH water downstream is achieved. This technique was successful with no cost since it required only a change in operation. Hammond Lake in NAB was operated in a similar manner to increase the pH in Tioga Lake. This technique was also reported to be successful at no costs.

Nitrogen Supersaturation

25. Nitrogen supersaturation in tailwaters was reported from three Columbia River projects. These hydropower projects (The Dalles, John Day, and Bonneville) release flows that entrain large quantities of air before submerging in the tailwater, thus forcing nitrogen gas into solution. In all three cases, the trajectory of the release was modified with a spillway deflector to minimize submergence of releases such as those shown in Figure 7. By preventing submergence of the release in the tailwaters, the pressure that previously forced the entrained air into solution is reduced significantly.

26. The results of prototype tests using a spillway deflector at Lower Monumental Dam are shown in Figure 8. As the discharge from the project increased, the percent saturation also increased; however, the deflector reduced saturation levels by as much as 15 percent. A considerable amount of information was reported to be available on this technique; however, the technique was evaluated as marginally successful.

Miscellaneous

27. Jennings Randolph Lake in NAB was reported to have organic sediment accumulation downstream that impacted the benthos. Selective withdrawal along with flow augmentation was used to improve downstream water quality. This was reported to be successful with no costs.

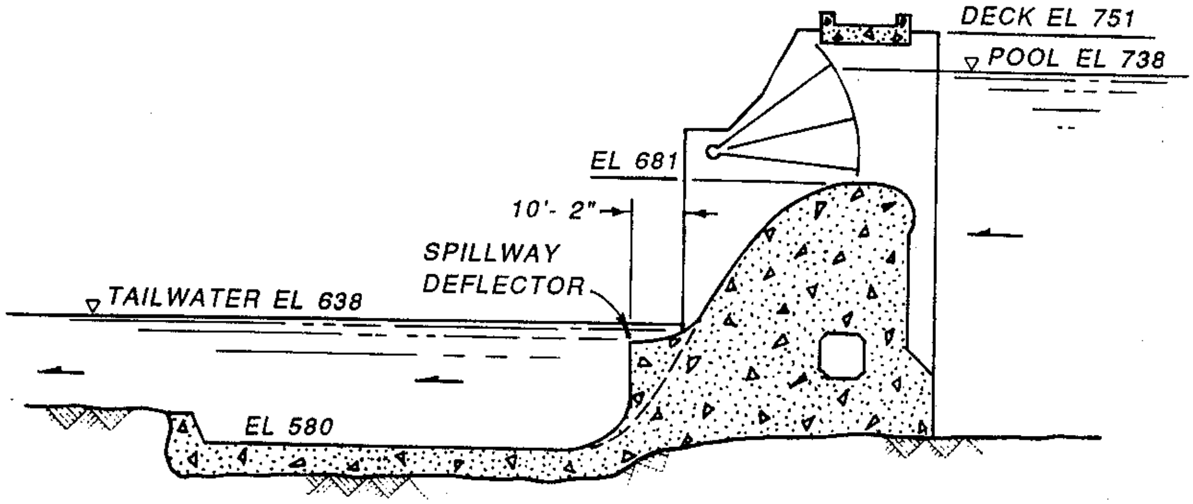

Figure 7. Proposed spillway deflector for Lower Granite spillway (from Rulifson and Abel (1972))

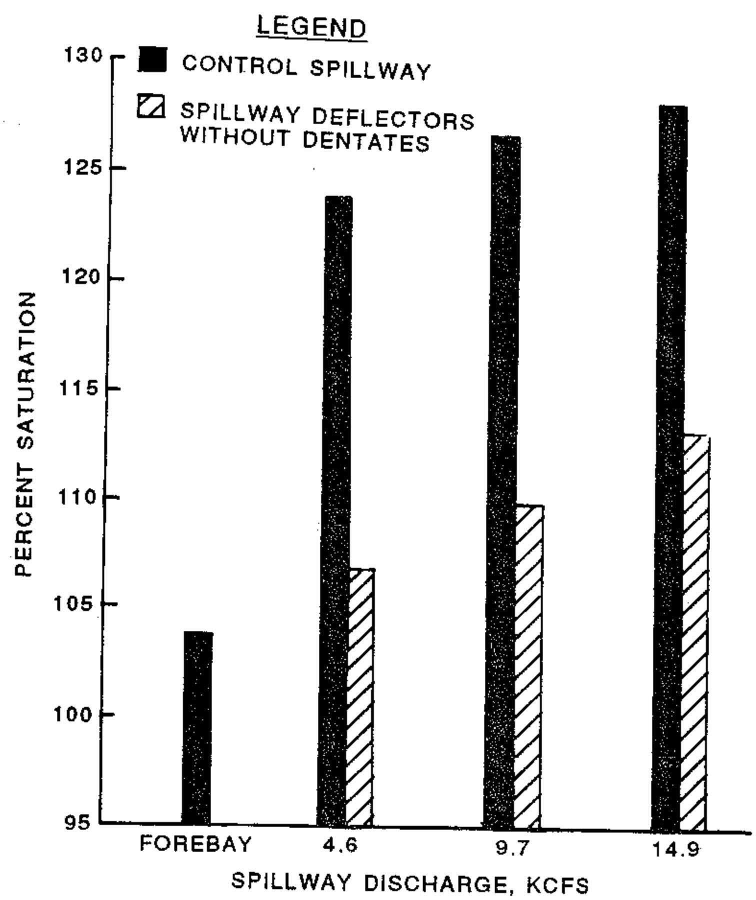

Figure 8. Average nitrogen concentrations of forebay, control spillway, and spillway deflectors at three separate flows, 29 March 1973, Lower Monumental Dam (Ebel et al. 1973)

28. Lake Oahe in MRO was reported to experience difficulty with flow conveyance as the result of ice formation downstream during the winter. Localized mixing and selective withdrawal were investigated as potential techniques to release warmer water. However, an operational modification is currently being evaluated to correct the situation.

PART III: LAKE ENHANCEMENT NEEDS AND CORRECTIVE TECHNIQUES

29. Water quality concerns reported for reservoirs were more varied than those reported for tailwaters. Seven categories of concerns were identified (Table 2), with turbidity and suspended solids as the most commonly reported area of concern. Impacts to the fishery, algae, or water quality because of turbidity were reported by 20 projects. Eutrophication-related concerns, which included taste and odor concerns (usually Mn and H_2S), anoxic hypolimnia, and algae blooms, were reported from 11 projects. Other concerns included aquatic macrophytes, acid mine drainage, and single occurrence concerns (TDS, leaking oil wells, and Hg).

Turbidity and Sedimentation

30. Carlyle Lake in LMS experienced difficulty with sedimentation reducing the pool depth in marinas for recreational uses. Dredging was used to remove the sediment buildup and restore the pool depth. Almond Lake in NAB also experienced a loss of recreation and flood-control storage as the result of sedimentation. This concern was addressed by raising the pool 5 ft. No technical evaluation of this technique was given.

31. Walla Walla District reported excessive turbidity in Mill Creek Lake with high nutrient levels and low DO in the hypolimnion as a result of turbid inflows. Since pool water quality was dependent on inflow quality, these concerns were successfully eliminated through modification of operational procedures. This involved filling the pool after the peak runoff period, thereby allowing the turbid inflows to be routed through the pool.

32. Blue Mountain Lake in SWL was also reported to have turbidity levels that were successfully controlled by operational techniques involving periodic drawdowns (every 10 years) and planting of grasses by the State Game and Fish Commission. This technique allowed the sediments to aerate and consolidate, thereby reducing the resuspension of sediment in the water column. Once the pool was restored to the normal level, the decomposition of the grasses increased the nutrient levels in the water column. This resulted in positive impacts on the fishery with some reduction in turbidity.

33. Lake Chicot in LMK suffered from high turbidity, suspended solids, and nutrients (Price 1986, Johnson 1988). Although a number of techniques were examined, flow diversion was used to control turbid inflows. A

6,500-cfs-capacity pump plant was constructed on the major inflow to the lake to pump inflows away from the lake and to the Mississippi River. This technique was successful in reducing turbidity.

34. Omaha District indicated concerns with high turbidity levels that severely degraded water quality. Eleven projects (Pawnee Lake, Branched Oak Lake, Holmes Park Lake, Twin Lakes East Branch, Twin Lakes West Branch, Conestoga Lake, Yankee Hill Lake, Stagecoach Lake, Wagon Train Lake, Blue Stern Lake, and Olive Creek Lake) reported a loss of fishery resources as the result of sediment covering fishery habitat. Location of the turbidity was not limited to the pool but extended to the tributaries and the watersheds for each lake. Although various techniques are being considered, only lake drawdown, with cultivation of aquatic plants along the shoreline to prevent erosion, and land treatment in the watershed were reported as the most likely techniques to reduce the excessive turbidity.

35. Portland District reported a concern with turbidity in Hills Creek Reservoir, Foster Reservoir, and Green Peter Reservoir. This concern was due to logging and road-building in the watershed which exposed erodible soils that contributed sediment and nutrients to the lake during runoff. As with turbidity concerns at other projects, the turbidity was manifested throughout the watershed and tributaries. Control techniques have not been implemented.

36. A similar concern was reported at Broken Bow Reservoir in SWT. Clearcutting in the watershed has contributed to decreasing water clarity and deoxygenation of the hypolimnion in the upper portion of the reservoir, but no techniques have yet been implemented to alleviate the situation.

Eutrophication

37. Lake eutrophication concerns were described for several projects. These concerns, which are the result of accelerated nutrient enrichment, were corrected by various methods. St. Louis District reported concerns with taste and odor at the entrances to water supply intakes because of eutrophication processes in Rend Lake. The area near the intakes was treated with copper sulfate to control algae blooms. This procedure was reported to be marginally successful.

38. Fern Ridge in NPP exhibited accelerated eutrophication processes with nutrient enrichment from the watershed that lead to algal blooms and excessive macrophyte growths. The location of the nutrient enrichment

extended from the watershed and tributaries to the pool; however, no action has yet been taken to correct the concern.

39. Bowman Haley Reservoir in MRO was listed as highly eutrophic with ectogenic meromixis and severe algal blooms that diminished reservoir recreation. Along with the algal blooms, a buildup of sulfates that create severe water quality conditions has been identified in the pool. The technique chosen to alleviate this concern was hypolimnetic withdrawal using an Olszewski tube (Olszewski 1961). This tube was to be attached to the existing outlet structure and to extend to the deeper portions of the hypolimnion, thus allowing withdrawal of the hypolimnion with minimal impact on the stratification. Although this project was not completed at the time of this report, it was estimated by MRO to cost $100,000.

40. Releases from Prado Lake in Los Angeles District are made to supply ground-water recharge facilities downstream. Although this project was not authorized for water supply, the retention of water in Prado Lake creates concerns with ammonia, manganese, nitrogen, and TDS accompanying low DO in the pool. The magnitude of the water quality concerns in the pool increases with the retention time. However, enhancement techniques have not been attempted.

41. Willow Creek Reservoir in NPP also reported concerns with hypolimnetic anoxia and H_2S. Although a hypolimnetic aeration system was proposed to remedy the situation, technical evaluation of the proposed system was not complete at the time of the survey.

42. West Thompson Lake in New England Division (NED) was reported to have severe algal blooms in the pool that extended into the tailwater. To reduce the concentrations of algae, an operational technique was tested in which the pool elevation was fluctuated by raising it 2 ft and then dropping it quickly in hopes of flushing the surface water containing the algal. This technique was only marginally successful in reducing the algae concentrations.

43. Fort Peck Lake in MRO displayed chronic algal blooms. A blue-green algal bloom was concentrated (by wind action) in an embayment that was used as a source of potable water. The technique chosen to mitigate this algal bloom was to move the intakes deeper and further out into the lake. This technique was still under study at the time of the survey. Portland District also expressed concerns with algal blooms during the summer in Dexter Reservoir; however, no action has yet been taken to address this concern.

44. Cherry Creek Reservoir in MRO experienced deteriorating water quality as a result of rapid urbanization. This reservoir receives considerable

recreational visitation (it is located in the Denver area). To slow the inflow and improve the water quality before entering the lake, wetlands will be placed at every storm sewer entrance to the project property. Since the project was not completed, technical evaluation was not given.

45. East Sidney Lake and Whitney Point Lake in NAB also suffered from eutrophication. Infrared aerial photographs of both watersheds allowed identification of nonpoint sources, land-use patterns, and the location of highly eroded areas. These data will assist State and local agencies in establishing watershed control measures. Both projects are under continued investigation.

46. Although eutrophication was not indicated, Huntington District (ORH) reported a concern with stratification in Beech Fork Lake, which created a shallow epilimnion and anoxic hypolimnion. This condition had a negative impact on the reservoir fishery. Destratification of the lake was used to increase the DO in the hypolimnion (Punnett 1988). Temperature and DO isoplots for the 1987 stratification period appear in Figure 9. This technique involved the use of axial-flow pumps that transported epilimnetic water into the hypolimnion to maintain a well-mixed environment. This technique was

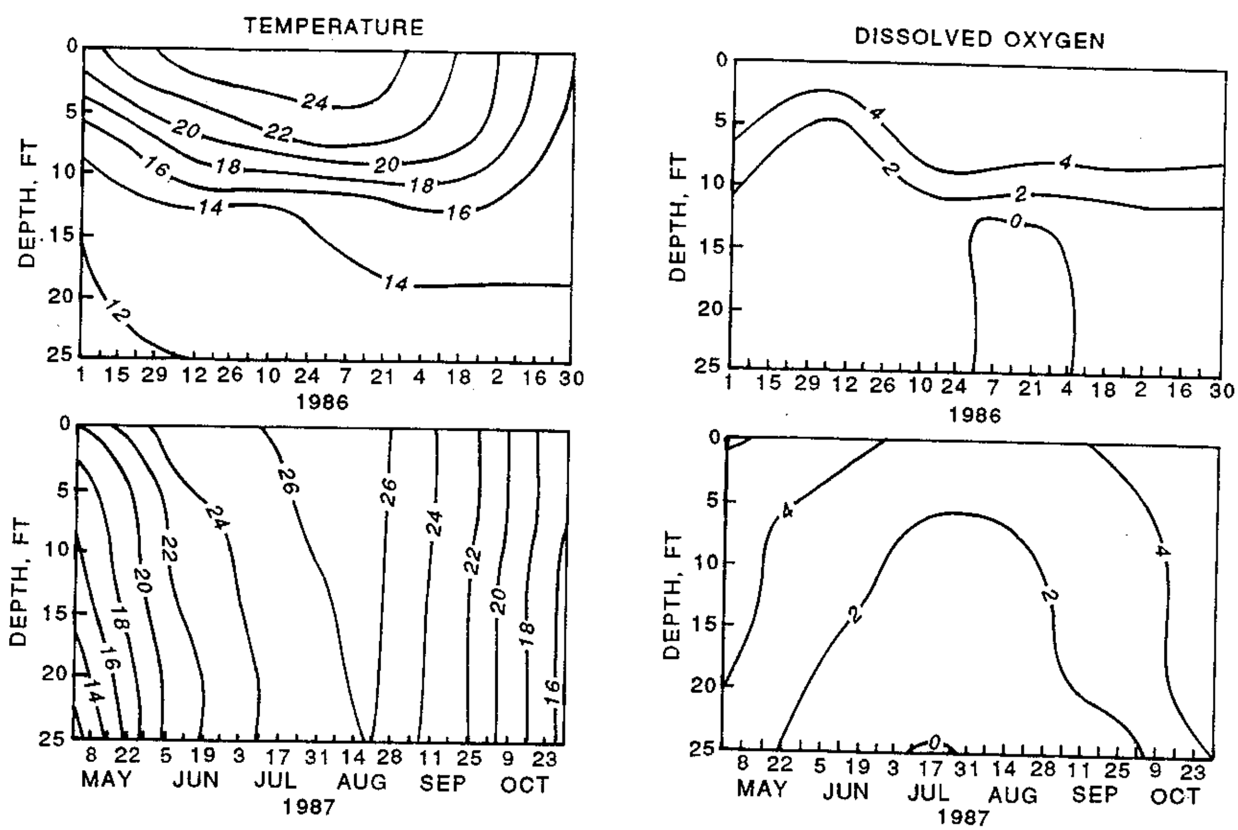

Figure 9. Temperature isoplots for Beech Fork Lake before (1986) and after (1987) lake destratification (from Punnett (1988))

implemented using ORH expertise to design the system, which cost approximately $25,000. Initial technical evaluation indicated the procedure was successful, but it was still under investigation.

47. Fort Worth District also reported concerns with low DO in the hypolimnion of Grapevine Lake during the summer. This situation increased Fe and Mn concentrations in the tailwater, which is used for water supply by the city of Grapevine. The local government installed a destratification system consisting of a 150-SCFM compressor and diffuser to prevent anoxia. This technique relies on the rising bubble columns to upwell hypolimnetic water to the surface for reaeration. Technical evaluation indicated it was marginally successful at an approximate cost of $37,600. The marginal success was due to late activation of the system after the lake had stratified.

Macrophytes

48. Excessive aquatic macrophyte growths have been listed as a significant concern in several projects. These growths create difficulties for recreation as well as other project purposes. A relatively small portion of Lake Barkley (50 acres) in ORN had difficulty with Eurasian watermilfoil impacting recreation. An application of herbicide was scheduled to control the infestation. Vicksburg District also reported concerns with aquatic weeds in Lake Ouachita and used herbicides to control the infestation. In addition, triploid grass carp were stocked to help control the weeds. No evaluation of the effectiveness of the technique was made.

49. Buffumville Lake in NED was reported to have excessive stands of *Myriophyllum* spp., but these have been controlled by spraying with Silvex. This was deemed only marginally successful since there was a temporary reduction of the weeds. East Brimfield Lake, also in NED, had a similar situation, but in addition to spraying with Silvex, the lake was raised 2 ft in the summer to drown the weeds followed by a drawdown in the winter to freeze them. This technique was also listed as marginally successful in reducing the weeds.

50. Pat Mayse Reservoir in SWT has difficulty with *Myriophyllum* spp. restricting boating and swimming. Aquathol was used with marginal success in controlling the weeds. Wappapello Lake in LMS experienced nuisance growths of brittle Naid. Since a large portion of the lake was covered, chemical control, in conjunction with lake drawdown, was used to control the Naid; this reportedly met with marginal success.

Watershed and Acid Mine Drainage

51. A number of projects were reported to have difficulty with water quality as a direct result of activities in the watershed. Beaver Lake in SWL has experienced eutrophic conditions caused by high levels of nutrients entering the lake from nonpoint sources. These conditions have increased the cost of water treatment for municipal and industrial water supply. Best management practices were proposed to control erosion and reduce nonpoint discharge of nutrients.

52. Loyalhanna Lake in Pittsburgh District (ORP) suffered from coal mine drainage that contributed high concentrations of iron oxide to the lake. This condition not only impacted the lake but also the water supply intake downstream of the lake. An operational technique was used to improve the condition. A minor increase in pool elevations in 1974 increased the hydraulic residence time and allowed the iron oxides to settle in the upper portion of the pool. A comparison of inflow and outflow Fe for the periods before and after the pool raise indicated a decline in Fe concentrations in the release. Although some loss of terrestrial habitat resulted from the higher pool elevations, this technique was deemed successful at little or no cost.

53. Three other projects in ORP reportedly suffered from acid mine drainage: Conemaugh River Lake, Tygart Lake, and Allegheny Reservoir. Conemaugh was operated in coordination with Allegheny Reservoir and other projects on the Allegheny River Basin to control acid mine drainage contributions from the Kiskiminetas River. Conemaugh was operated to retain mine drainage until sufficient dilution and neutralization water was available in the Allegheny River to assimilate the Conemaugh releases. This technique was reported to be successful in controlling the acid mine drainage. Slugs of acid mine drainage from Three Fork Creek and the West Fork River, tributaries to the Monongahela River, were diluted with timed increases in releases from Lake Tygart. Aylesworth Creek Lake in NAB was reported to suffer from acid mine drainage, low nutrients, and low pH. The State of Pennsylvania fertilized and limed the lake to improve the fishery. This technique was successful at an approximate cost of $750,000.

54. East Branch Clarion River Lake in ORP has been the location of several techniques to improve lake water quality. Selective withdrawal operations were used to route low pH water through the reservoir to minimize impacts to the productivity of the lake. In addition, periodic emergency

liming of the lake was necessary to control the pH. Experiments with fertilization of an embayment were also reported along with introduction of forage for lake trout (smelt and mysis shrimp). These were reported to be successful with a total annual cost of approximately $2,000.

Miscellaneous Pollutants

55. Lake Audubon in MRO was reported to have high concentrations of TDS as a result of surface evaporation. This high concentration of TDS was corrected by water exchange with Lake Sakakawea to dilute the TDS concentration. This technique was successful and improved the fish spawning habitat and also minimized ice gouging on islands in the reservoir.

56. Oologah Lake in SWT was reported to suffer from leaking oil wells in the Lake. This problem is being corrected by plugging the wells with impervious material as funds become available. Another unique concern exists at Cottage Grove Reservoir in NPP: Hg contamination in fish as a result of erosion of natural deposits of mercuric sulfide which were transported to the reservoir. The Hg was located throughout the watershed, tributaries, and pool. Corrective techniques have not been attempted as of this writing.

PART IV: ENHANCEMENT NEEDS AND CORRECTIVE TECHNIQUES FOR LOCK AND DAMS

57. Although the hydraulic residence time of lock and dams is much shorter than reservoirs, lock and dam projects may exhibit many of the situations encountered with reservoir projects. A number of lock and dam pools in ORP (Montgomery, Emsworth, New Cumberland, Pike Island, Hannibal, Hildebrand, and Opekiska Lock and Dams) exhibit low DO during the summer low-flow periods. Water quality surveys indicate that the release from these projects at times provides considerable reaeration to the river, as indicated by the increased DO observed below each structure (Figure 10).

58. Field investigations conducted in 1971 at Montgomery Lock and Dam indicated that a 2-ft gate opening on one gate achieved 1.5 times the DO downstream as two gates open 1 ft (US Army Engineer District, Pittsburgh 1975). Therefore, operation of the spillway gates to further increase reaeration during low-flow periods was accomplished by operating the minimum number of gates

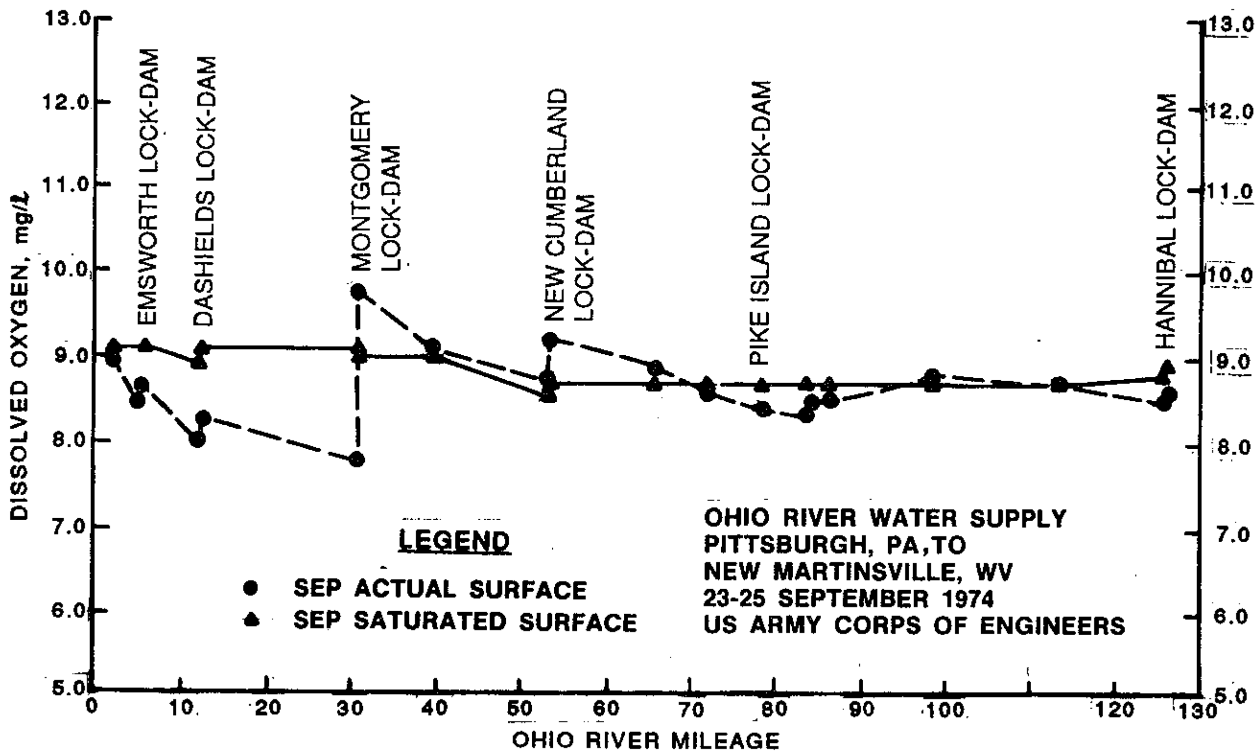

Figure 10. Ohio River DO and saturation concentration from Pittsburgh to New Martinsville for September 1974 (from US Army Engineer District, Pittsburgh (1975))

to achieve the highest flow possible through a gate, rather than lower but equal discharge through all gates. This successful technique involved only a modification of operation at these structures. This type of operation can be detrimental to energy dissipation in the stilling basin and cause scour downstream. Therefore, the impacts of this type of operation on the stilling basin should be investigated prior to implementation of this technique.

PART V: SUMMARY

59. The CE Districts are responsible for water quality management at their projects. To this end, the Districts use a variety of techniques to achieve management objectives. Districts were surveyed for water quality concerns for which enhancement techniques were planned or attempted. Ninety-seven responses from 17 Districts were categorized by location of the water quality concern (tailwater, pool, or lock and dam). Twenty-eight different enhancement techniques were identified with some projects listed as still under investigation. Of the categories of techniques, operational methods were reported to be the most successful.

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APPENDIX A: QUESTIONNAIRE USED TO SURVEY DISTRICTS FOR WATER QUALITY ENHANCEMENT TECHNIQUES

WATER QUALITY MANAGEMENT FOR RESERVOIRS AND TAILWATERS DEMONSTRATION

QUESTIONNAIRE

Section A : PROJECT DESCRIPTION

1. Project Name: ______________________________

2. District Code: __________

3. District Point of Contact:

   Name: ____________________ Office Symbol: ____________

   Phone: (FTS) ____________ (Commercial) ____/__________

4. Project Location:

   Latitude: ___/___/___ Longitude: ___/___/___ State: __________

5. Basin Description:

   River on which Structure is Located: ______________
   River Mile at Structure: ______________
   Local Drainage Area (square miles): ______________
   Project Drainage Area (square miles): ______________
   Total Drainage Area (square miles): ______________
   Major Inflow Tributary: ______________
   Other Important Tributaries: ______________
   Primary River Confluence: ______________
   Secondary River Confluence: ______________
   Watershed Landuses:
   Natural: _____(%) Agriculture: _____(%) Industrial/Urban: _____(%)

6. Project Uses:

   Project Authorizations (Check where Appropriate)
   ___ Flood Control ___ Hydropower ___ Low Flow Augmentation
   ___ Navigation ___ Water Supply ___ Fish and Wildlife
   ___ Water Quality ___ Irrigation ___ Recreation
   ___ Other: ______________

   Percent of Project Authorized for Water Quality Purposes: ________ (%)

   Designated Uses (Check where Appropriate)
   ___ Primary Water Contact ___ Fish and Wildlife ___ Water Supply
   ___ Secondary Water Contact ___ Other: ______________

   Total Number of User Man-days per Year: ____________ Man-days/year

7. Reservoir Features:

	Elevation (NGVD)	Surface Area (Acres)	Storage (Acre-feet)
Streambed at Dam		0	0
Minimum Pool			
Recreation Pool (Top)			
Max. Power Pool (Top)			
Conservation Pool (Top)			
Flood Control Pool (Top)			
Max. Spillway Design			
Other (________)			
Other (________)			

8. Operational Description:

Type of Release Structure	Centerline Elevation (feet, NGVD)	Percent of Annual Flow (Percent)
Uncontrolled Spillway (Length: ______, feet)		
Water Quality Intake		
Gated Spillway		
Hydropower Intake		
Flood Control Intake		
Other (________)		
Other (________)		

Turbine Type: __________ Maximum Capacity (Mw): __________

Check One: ___ Peaking Operation or ___ Baseload Operation

Check if Appropriate: ___ Pumped Storage Operational ___ Reregulation Pool Downstream

Average Annual Pool Volume (acre-feet): __________

Average Annual Total Discharge (acre-feet/year): __________

Minimum Tailwater Elevation (feet, NGVD): __________

Maximum Tailwater Elevation (feet, NGVD): __________

Section B : WATER QUALITY DESCRIPTION

1. Water Quality Classification: ____ 2. Trophic State Classification: ____

3. Water Quality Evaluation:

Water Quality Consideration	Tributary			Pool			Tailwater			Remarks
	a	b	c	a	b	c	a	b	c	
1. Iron										
2. Manganese										
3. Low D.O.										
4. Hydrogen Sulfide	X	X	X							
5. Turbidity										
6. Low Flow	X	X	X	X	X	X				
7. High Flow	X	X	X	X	X	X				
8. Fluctuating Flow	X	X	X	X	X	X				
9. Low Temperature										
10. High Temperature										
11. Fluctuating Temp.				X	X	X				
12. Dissolved Solids										
13. Metal Contaminant										
14. Organic Contamin.										
15. Gas Supersaturat.	X	X	X	X	X	X				
16. High Nutrients										
17. Algae										
18. Macrophytes										
19. Sediment Accum.										
20. Drawdown	X	X	X				X	X	X	
21. Pool Elev Fluct.	X	X	X				X	X	X	
22. Shore Eros.										

3. Water Quality Evaluation (Continued):

Water Quality Consideration	Tributary			Pool			Tailwater			Remarks
	a	b	c	a	b	c	a	b	c	
23. Taste and Odor										
24. pH/Acidity										
25. Bacteria										
26. Parasites										
27. Other (_________)										
28. Other (_________)										
29. Other (_________)										
30. Other (_________)										

4. Water Quality Monitoring Evaluation:

Number of Routinely-sampled Stations: _____

General Location of Rountinely-sampled Stations (Check where Appropriate)

___ Inflow   ___ Upper Pool   ___ Mid Pool   ___ Lower Pool
___ Discharge   ___ Tailwaters   ___ Other

Number of Routine Sampling Trips per Year: _____

Months when Routine Sampling Occurs (Check where Appropriate)

___ Jan   ___ Feb   ___ Mar   ___ Apr   ___ May   ___ Jun
___ Jul   ___ Aug   ___ Sep   ___ Oct   ___ Nov   ___ Dec

5. Parameter List (Check where appropriate):

Parameter Type	Profile	Surface	Strata	Composite	Not Sampled
In situ variables					
Major nutrients					
Phytoplankton					
Zooplankton					
Metals(Fe, Mn)					
Heavy metals					
Organic contaminants					
Other (___________)					

Data Storage (Check where Appropriate)

___ STORET   ___ Mainframe database   ___ PC database   ___ Paper

Section C : ENHANCEMENT TECHNIQUE DESCRIPTION

1. Problem Description:

   Problem Address: ____________________
   Associated Problem(s): ____________________
   ____
   ____

   Brief Problem Description: ____________________
   ____
   ____
   ____
   ____

   Who Identified Problem?
   ___ CE
   ___ Other Federal Agency
   ___ State or Local Agency
   ___ Public
   ___ Other: ____________

   Location of Problem:
   ___ Watershed
   ___ Tributary
   ___ Pool
   ___ Tailwater
   ___ Other: ____________

2. Technique Description:

   Technique Used: ____________________
   Enhancement Objective: ____________________
   ____

   Brief Technical Description: ____________________
   ____
   ____
   ____
   ____

   Source of Information on Technique (Check where appropriate)
   ___ In-house Expertise
   ___ CE Technical Reports
   ___ Other Technical Literature
   ___ Contracted Expertise
   ___ Other Government Agency
   ___ Other: ____________

3. Technical Evaluation (Check where appropriate)

   ___ Successful
   ___ Unsuccessful
   ___ Marginally Successful
   ___ No Assessment Made

   Cost: ____________

4. Impact Assessment:

   Positive Impacts: ____________________
   ____

   Negative Impacts: ____________________
   ____

5. Bibliographic Data Available: ____________________
   ____
   ____
   ____
   ____
   ____
   ____

Section D : REMARKS

Section Item Remarks